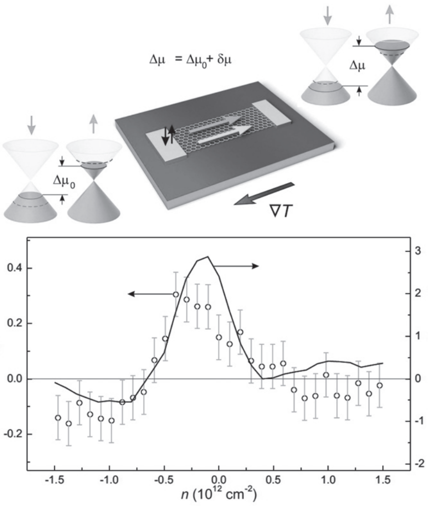

Fig 2. (a) Spin-up and spin-down channels have different associated Seebeck coefficients due to the spin accumulation resulting from spin injection. This leads to the generation of a thermoelectric spin voltage, and the change of the nonlocal spin transresistance, driven by the (hot) carrier temperature gradient (b). See Ref. [6].

CONTRIBUTED PAPERS

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HB-08. Cascaded All-Carbon Spin Logic based on Graphene Nanoribbon Magnetoresistance.

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The development of a computing system that efficiently exploits spintronic devices requires a technique for directly cascading [1] the output of one spintronic switch to the input of another spintronic switch. In the absence of such a direct cascading mechanism, additional circuitry is necessary to convert the output of one device into a form that can be utilized as the input of another device. This conversion/amplification circuitry must generally be implemented with conventional electronics, thereby reducing the improvement derived from the spintronic devices and preventing the full exploitation of the spintronic devices. All-carbon spin logic [2] provides a direct cascading mechanism [3,4] necessary to efficiently exploit the extremely large magnetoresistance [5] demonstrated in zigzag graphene nanoribbons (GNRs) without additional cascading circuitry. In all-carbon spin logic, input carbon nanotubes (CNTs) are positioned alongside both edges of a zigzag GNR. The currents through the CNTs control the edge magnetization of the GNR, thus controlling the GNR magnetoresistance. Output CNTs are connected to both ends of the GNR in this all-carbon system, with a constant voltage bias applied to each CNT-GNR-CNT path. Therefore, the current through the input CNTs modulates the current through the output CNTs. Cascading is achieved by using the output CNTs of one all-carbon spin logic gate as the input CNTs that control the GNR magnetoresistance in other all-carbon spin logic gates. Individual GNR gates naturally perform the OR and XOR functions, which can be cascaded to perform any complex logic function. In addition to its compact nature resulting from the use of low-dimensional carbon materials, the dependence of the speed on electromagnetic wave propagation provides the potential for extreme high-speed (clock frequencies above 1 THz) and energetically-efficient (100x reduction in power-delay product) computing systems.

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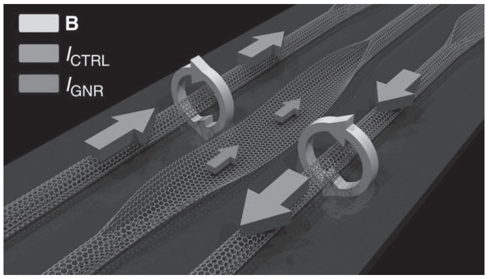

Fig. 1. Logic gate with graphene nanoribbon output current controlled by adjacent carbon nanotube input currents (from [2] under CC BY 4.0).

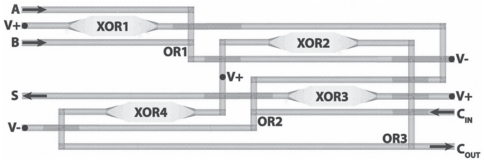

Fig. 2. All-carbon spin logic one-bit full adder comprised of four GNR-CNT XOR logic gates and three CNT wired-OR logic gates (from [2] under CC BY 4.0).

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HB-09. Proximity magneto-resistance in graphene induced by magnetic insulators.

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Graphene is a two-dimensional (2D) material that has attracted a lot of interest in view of its unique physical properties and applications potential in diverse fields. When it is placed on top of a magnetic insulator (MI), it can acquire spin polarization [1]. This mechanism results from the hybridization between p_z orbitals in graphene with those of the neighboring substrate. Evidence of this effect is the emergence of exchange splitting in the graphene band structure reported experimentally [2,3] and theoretically [1,4]. Here we demonstrate the existence of Giant proximity magnetoresistance (PMR) effect in a graphene spin valve. PMR calculations were performed for yttrium iron garnet (YIG), cobalt ferrite (CFO), and two europium chalcogenides EuO and EuS. The spintronic device studied consist of two magnets on top of a graphene sheet with two leads attached L_1 and L_2. The magnets have a length L, width W and are separated by a distance d as shown in Fig. 1a. We find a significant PMR (up to 100%) values defined as a relative change of graphene conductance with respect to parallel and antiparallel alignment of two proximity induced magnetic regions within graphene. Namely, for high Curie temperature (Tc) CFO and YIG insulators which are particularly important for applications, we obtain 20% and 76% at room temperature, respectively. For low Tc chalcogenides, EuO and EuS, the PMR is 100% in both cases, as shown in Fig. 1b. Furthermore, the PMR is robust with respect to system dimensions and edge type termination. Our findings show that it is possible to induce spin polarized currents in graphene with no direct injection through magnetic materials. We acknowledge EU Programme Graphene Flagship.

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